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Assessment of a photovoltaic pumping system in the areas of the Algerian Sahara

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Abstract

We present a methodology to analyze the performance of a photovoltaic system of pumping installed in an isolated site at Ghardaïa (southern of Algeria). A computer program which simulates the electric operation of the system (irradiation and production of water) on the hourly basis was developed while being based on the data of irradiation of the site of year 2005, measured with a step of 5 min. This work allows to evaluate the economic interest of the system which will have to satisfy an average daily volume of 60 m^3 throughout the year compared to another very widespread energy system in the area, the diesel genset (DG), by using the method of the life cycle cost (LCC). Considering the economic realities of the Algerian market where the price of the fuel is very low, it makes it difficult to other energy processes to emerge.

Keywords: Saharan location; Pumping of water; PV system; DG system; Life cycle cost

Contents

1. Introduction

As related by certain authors [1], the groundwater is a major source for the drinking water and the irrigation for the arid areas which constitute more than 70% of the surface of Algeria. In

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these areas the groundwater is being the only alternative, used by local population to supply itself for drinking water for their own consumption and irrigation of their garden, considered as means of subsistence. In the majority of the cases, water is pumped by electric motor-pumps supplied with the diesel genset (DG) of low power [2], and which constitute more than 80% of means of pumping used in these areas.

As in many of developing country, to satisfy the increasing demand of water, more well were dug and electrified, increasing by this fact the demand for electricity and fuel [1]. At the beginning of the nineties, the social character of this type of hydraulic activity, many projects were launched to equip these wells with motor-pumps powered by the electric network or DG. This operation very quickly became a total failure as the costs of exploitation and maintenance was at the charge of the local population. Which led, consequently, to the shut-down of these systems.

However, there exists in Algeria a substantial potential for the use solar photovoltaic (PV) energy for pumping of water to be used for drinker and irrigation and therefore to improve the living conditions in these arid areas [3–10]. Efforts are being realized in Algeria to satisfy the requirements of water supply by PV systems for pumping, but in the absence of a real political willing, it will be hard to go through. According to the majority of the authors [1,11–13] the financial viability of solar PV energy with respect to the other conventional options, electric or DG, for the pumping of water is the principal barrier which slows down its broad adoption.

Users prefer to use the traditional and conventional means, such as DG. However, the support of the price of the fuel by the state makes the use of the water pumping by the DG more attractive and then limiting the emergence of the solar energy even in favorable zones.

The aim of this work is to analyze the performance of a PV pumping system to be installed in an isolated site at Ghardaïa, south of Algeria (lat. 32°38′N; long. 3°67′E; alt. 530 m). A computer program simulating the electric operation of the system (irradiation and production of water) on the hourly basis was developed while being based on the data of irradiation of year 2005 measured with a step of 5 min. This work is used to evaluate the economic interest of the PV system which will have to satisfy a mean daily volume of 60 m^3 throughout the year as compared to a DG system, by using the method of the life cycle cost (LCC). Also, it is used to define using various scenarios, favorable elements or on the contrary obstacles with the use of PV systems on a large scale in these areas.

2. Description and sizing of PV system

In addition to their great reliability of operation, the PV pumps are adopted in the last two decades [12] and mostly used in isolated areas. The PV system must satisfy the needs estimated of water which are 60 m^3 per day. The scenario of the most critical month from the point of view irradiation [14] and a constant load [4,15], i.e. a constant daily need of water, was chosen.

Although PV systems of pumping with direct coupling, using a continuous motor-pump group, were studied and their performances proven [8,16–18], for practical reasons, such as the availability, the high price… the choice was made on a system standard 3-phase alternative current (ac) which use any source of energy.

In comparison with direct current (dc) motors, the motors with induction are very solid, reliable and maintenance free [13,17,19–21]. The results of sites using for the ac systems of pumping showed encouraging figures of performance [22,23]. The ac system naturally requires an inverter to pulse width modulation (PWM) [24].

The system studied in this paper is a PV system of pumping which consist of a PV array, an inverter dc/ac 3-phase to PWM and an ac motor-pump 3-phase. The water pumped is stored in a tank.

The most delicate phase relates to the sizing and the optimization of the PV system of pumping which is a very complex task because of the variability of parameters of entry. Several works on the sizing of PV systems were published [4,5,9,25]. These works are based on the simulation of the operation of each component of the PV System.

The sizing of PV array in terms of hydraulic power and solar irradiation is given by

$$P = \frac{\rho * g * h * Q * \eta_r}{G_T * \eta_{pv} * \eta_s} \tag{1}$$

where P is the electric power of the PV array (Wc), G_T the global irradiation on the PV array plane (kWh/m^2), η_r the array efficiency at the reference temperature (T_r = 25 °C), η_{pv} the PV array efficiency under the operations conditions, η_s the sub-system efficiency, Q the flow rate (m^3/h), h the total pumping head (m), ρ the water density and g is the acceleration due to gravity, where

$$\eta_{pv} = f_m[1 - \alpha(T_c - T_r)] * \eta_r \tag{2}$$

$$T_c = T_a + \frac{G_T}{800}(\mathrm{NOCT} - 20) \tag{3}$$

where f_m is the matching factor ($f \approx 0.90$), α the cell temperature coefficient 0.2 to 0.6%/°C (0.004 to 0.005%/°C for Si), T_r the reference temperature (T_r = °C), T_c the daily average cell temperature (°C) and T_a is the hourly ambient temperature (°C).

From Eq. (1), it is possible to determine the size necessary of PV array for a given pumping head and water need and to estimate the daily water quantity produced by the size of the array at a given irradiation.

3. Description of the models

3.1. Irradiation

The estimate of the hourly irradiation on a tilted surface we use the model of Liu and Jordan [26,27].

3.2. Array model

In the literature, there are several mathematical models describing the operation and the behavior of PV array [28–30]. These models are different by the process from calculation, the precision and the number of parameters intervening in the calculation of characteristic I–V.

A PV array is a nonlinear power source. At a given irradiance, the current–voltage relationship is given by

$$I = I_{\mathrm{ph}} - I_{\mathrm{s}}\left(\exp\frac{q(V+IR_{\mathrm{s}})}{mkT} - 1\right) - \frac{V+IR_{\mathrm{s}}}{R_{\mathrm{sh}}} \tag{3}$$

with $V_{\mathrm{t}} = \frac{kT}{e}$, where I_{ph} is the photocurrent (A), I_{s} the saturation current (A), R_{s} the series resistance (Ω), R_{sh} the shunt resistance (Ω), m the diode quality factor, k the Boltzmann's constant (1.38×10^{-23} J/K), q the charge of electron, T the temperature of the solar cell (K), I the operation current (A) and V is the operation voltage (V).

The curve of characteristic I–V of Eq. (3) is only applicable at an irradiation (G_1) and temperature (T_1). Other models [5,31] are used to translate this curve with other irradiation (G_2) and temperature (T_2). They change any point (V_1, I_1) of this curve at a new point (V_2, I_2). The curve is translated as a template, without distorting its shape [5], according to the following equations:

$$I_{\mathrm{sc2}}(G_2, T_2) = I_{\mathrm{sc1}}(G_1, T_1)\frac{G_2}{G_1} + \alpha(T_2 - T_1) \tag{4}$$

$$V_{\mathrm{oc2}}(G_2, T_2) = V_{\mathrm{oc1}}(G_1, T_1) + mV_{\mathrm{t}}\ln\left(\frac{G_2}{G_1}\right) + \beta(T_2 - T_1) \tag{5}$$

$$I_2 = I_1 + \Delta I_{\mathrm{sc}} \tag{6}$$

$$V_2 = V_1 + \Delta V_{\mathrm{oc}} \tag{7}$$

$$\Delta I_{\mathrm{sc}} = I_{\mathrm{sc2}} - I_{\mathrm{sc1}} \tag{8}$$

$$\Delta V_{\mathrm{oc}} = V_{\mathrm{oc2}} - V_{\mathrm{oc1}} \tag{9}$$

To validate this model, characteristics I–V of PV module were compared with a variety of ambient conditions, with the curves defined by Eqs. (4–9), where a good fit of the measurement and simulation is obtained [5].

4. Economic study

The method of the LCC is most largely used to evaluate the financial viability of a system [1,14,23,32,33]. Economic attempts to study pumping PV systems of pumping in Algeria were carried out [25], but in a very brief way.

In Algeria, the use of the renewable energy is still at the beginning in spite of the financing of several prototypes by the state. The major problems are certainly identified but very difficult to solve: high costs, customs taxes and more particularly the low price of the fuel. The price of the diesel liter to the pump costs 13.70 DA (1€ ≈ 100.00 DA), one of the lowest prices in the world.

In what follows, we will try to evaluate the LCC of a pumping PV system compared to another source of replacement as motor-pump powered by DG by taking account some of these financial parameters.

4.1. The initial costs

The initial costs include expenses done at the time of the installation of the pumping system. When the initial investment is repaid on the LCC of the system, annuities are calculated according to the repayment of the capital and the interest according to Eq. (10).

$$V_{\mathrm{ann}} = V_{\mathrm{init}}\left\{\frac{i(1+i)^n}{(1+i)^n - 1}\right\} \tag{10}$$

where i is the interest rate, V_{ann} the worth of the annuity and V_{init} is the initial cost of the equipment.

The annuity, so calculated, should be brought back to a value actualized at the time of the analysis of costs. It will be treated then as a recurrent cost.

4.2. The recurrent costs

The recurrent costs can divide expenses of working, maintenance and of repair and renewal. Some expenses are more periodic and can be brought back to annuities. Other costs represent the exceptional expenses that only occur some times during the lifetime of the system.

For the prompt expenses, one proceeds to a simple actualization of the present value of the component for the year of the expense by Eq. (11),

$$V_{\mathrm{as}} = V_{\mathrm{init}}(1+d)^{-n} \tag{11}$$

where d is the discount rate, V_{as} the actualized simple value of the component and V_{init} is the initial value of the component.

Eq. (12) permits us to bring back the value of annuities to a value actualized global (uniform actualization).

$$V_{\mathrm{au}} = V_{\mathrm{ann}}\left\{\frac{(1-(1+d)^{-n}}{d}\right\} \tag{12}$$

where V_{au} is the value actualized uniform of the annuity and V_{ann} is the initial value of the annuity.

When a governmental participation is considered with a subsidy of the capital, and so F is the fraction of the capital provided as subsidy, Eq. (12) becomes

$$V_{\mathrm{au}} = V_{\mathrm{ann}}(1-F)\left\{\frac{(1-(1+d)^{-n}}{d}\right\} \tag{13}$$

where F is the capital subsidy (subsidy rate (%)).

The assessment of these costs in relation to the volume of water pumped gives an indication of their viability in relation to the service that they will provide. According to the previous equations, we can note that the main parameters required for an economic assessment are the rate of discounts, subsidies, taxes, costs of component, costs of installation and the evaluation of costs of exploitation and maintenance.

4.3. Assessment of costs of a pumping system by diesel genset

To show the viability of a pumping PV system of, we should compare it with other conventional energy systems. For that, we calculate the cost of the m^3 of water pumped by the motor-pump unit supplied by a DG and having to satisfy same the daily requirements of water, by taking account of all the financial and economic parameters: cost of the fuel until the site of the well, the annual escalation of the price of the fuel, the lifetime of the system, maintenance and the replacement cost.

The cost of the yearly fuel is given by

$$\mathrm{AFC} = T_\mathrm{d} * F_\mathrm{d} * C_\mathrm{f} * 365 \tag{14}$$

where T_d is the number of operating hours of the DG system, C_f the diesel cost provides to the site of the well and F_d (l/h) is the estimated average consumption of diesel in the DG system.

Eq. (15) calculate the cost actualized of fuel on the lifetime of the system without escalation.

$$C_\mathrm{fl} = \mathrm{AFC} * \frac{[1-(1+d)^{-n}]}{d} \tag{15}$$

Eq. (16) calculate the cost actualized of fuel on the lifetime of the system with escalation.

$$C_\mathrm{fl} = \mathrm{AFC} * \frac{(1+e)}{(1+d)} \frac{[1-((1+e)/(1+d))^n]}{(1-(1+e)/(1+d))} \tag{16}$$

where e is the escalation rate and C_fl will be considered as profit for the PV system.

5. Results and discussion

5.1. Performance of the pumping PV system

While taking the cited models as a basis and the weather data measured during all year 2005 with a step of 5 min, a computer program has been elaborated for the calculation of the global irradiation on the PV array plane, and the electric and hydraulic performances of the PV system of pumping according to several parameters such as head, irradiation, ambient temperature, and power of PV array.

The areas of the South of Algerian benefit from a very significant irradiation. As illustrated in Fig. 1, we can see the importance of the daily hourly irradiation on the level inclined to the latitude of the location (on the plane of PV array) for December 2005 (December being considered as the most unfavorable month).

The daily average irradiation on the PV array plane is approximately 3800 Wh/(m^2 d). The daily average can reach 8000 Wh/(m^2 d) in particular during months from May to July with picks of 8400 Wh/(m^2 d). Another factor which is prejudicial to the good behavior and the efficiency of the PV array is the ambient temperature. We can see in Fig. 2, the daily hourly variations of the ambient temperature for the month of December 2005. Temperatures can be very high and reach 48 °C, in particular of month from May to September.

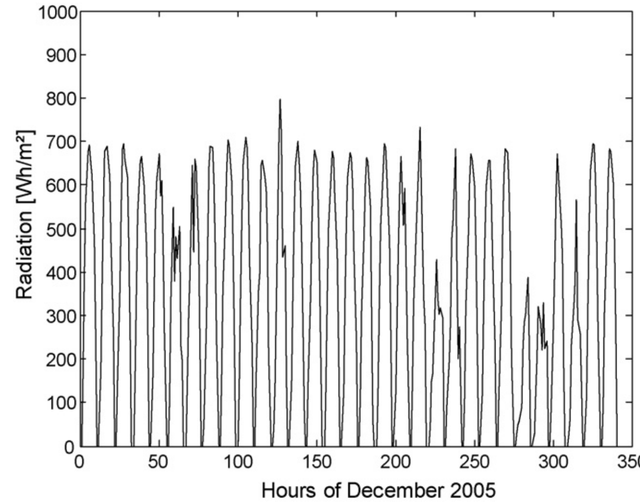

Fig. 1. Hourly daily irradiance on the plane of array PV—December 2005.

Table 1
Consistency of PV system of pumping

Designation	Capacity	Unit
PV array	2970	Wp
Inverter dc/ac (PWM)	4000	W
Submersible motor-pump	3000	W

To satisfy the daily needs in water (60 m^3) to a depth of 45 m, by taking account the characteristics of the site, the consistence of the pumping PV system is summarized in Table 1. The selected unit motor-pump whose pump is of centrifugal type must be submersible. By taking the characteristics provided by the constructor, the curve network is illustrated in Fig. 3. We can see that the unit motor-pump provides 14 m^3/h approximately to a height of pumping of 45 m with a substantial efficiency.

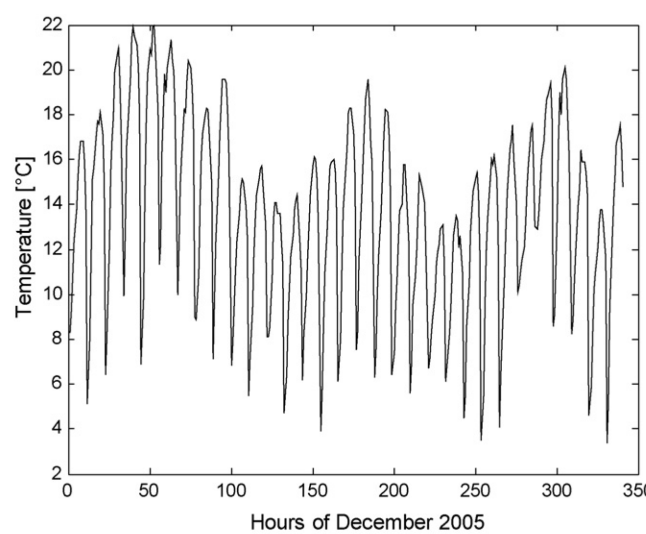

Fig. 2. Variation hourly daily of the ambient temperature—December 2005.

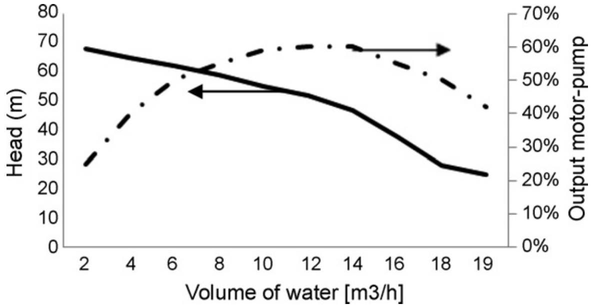

Fig. 3. Characteristics of motor-pump.

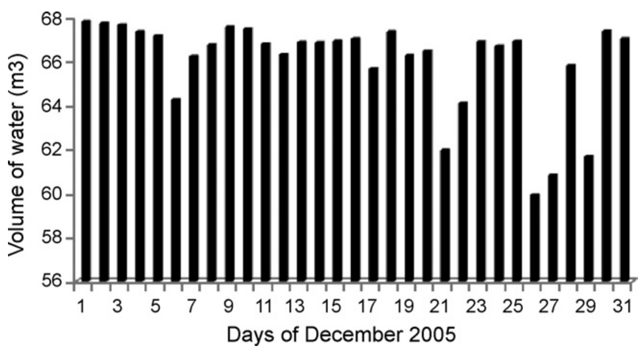

Fig. 4. Quantity of daily drawn water—December 2005.

On the importance of the irradiation of the site and a good approximation of the size of the PV array, we note according to Fig. 4 that the quantity of water drawn daily by the PV system of pumping satisfies the expressed needs. Fig. 5 shows the hourly volume drawn along the month of December. By putting forth the assumption of a constant consumption during all year and a utilization ratio of 100% of the system, the theoretical yearly needs in water rise to 21 900 m^3, as shown in Fig. 6, the PV system could provide 27 000 m^3 approximately. We note that the expressed needs could be annually satisfy with an important enough security margin.

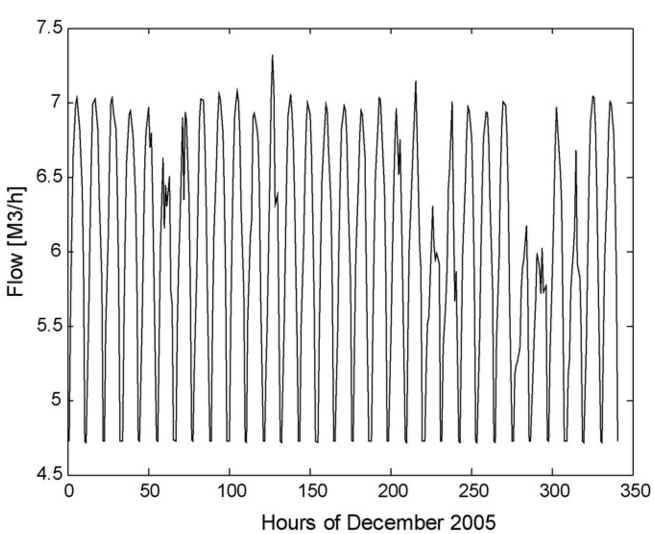

Fig. 5. Volume hourly drawn—December 2005.

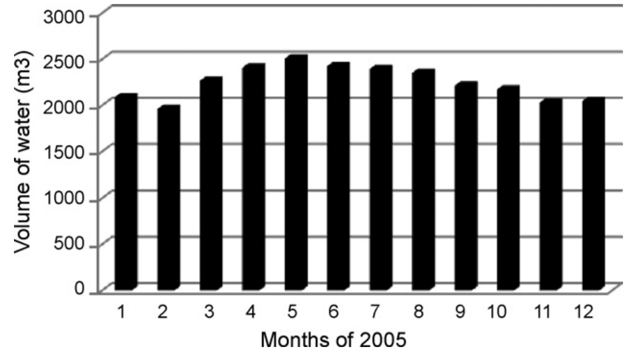

Fig. 6. Yearly quantity of water.

5.2. Economic analysis

In the second part of this work we try to compare the economic viability of the PV system and the DG system and to conclude the points of profitability showing the limits of viability of the PV systems by an analysis of sensitivity.

5.2.1. The life cycle cost

The three majors elements in costs of capital of a PV system of water pumping are: the PV array, unit motor-pump, and costs of installation. The storage of water and the system of distribution are ignored in this analysis (identical to all systems of pumping). On the other hand, costs of exploitation of the DG system constitute the main expense on the LCC of the system.

Table 2 presents the approximate costs of investment of the two options of water pumping. It is to note that all equipments constituting the two options are imported and available in Algeria. The different parameters of input used in the financial assessment are given in Tables 3 and 4.

To evaluate the LCC of the PV system, the period of analysis is supposed to be 20 years. Considering the hostile character of the site, the lifetime of the inverter and motor-pump unit is supposed to be equal to 7 years.

As regards to the DG system of pumping, the lifetime kept for an equipment of average quality is 7 years (by taking account daily operating time), with an escalation rate of the fuel cost of 5%. Maintenance costs of the DG system are estimated as a fraction of the capital cost. The annual average typical maintenance costs are 10% of the capital cost. If the payment is done the first year, the discount rate supposed is 8%. When the payment is done by annuities, the discount and interest rates are 10 and 8%, respectively, without taking account of inflation.

The flow of PV pump is entirely sensitive to the capacity of use of the system which will essentially depend primarily on the

Table 2
Capital costs of the two options of pumping of water

Systems	Capital cost (10^3 DA[a])
PV system of pumping	2847
Pumping by diesel genset	395

[a] US $1 = 78.00 DA (on 01/09/2007) and 1 € = 100.00 DA (on 01/09/2007).

Table 3
Technical parameters used in the financial evaluation

Parameters	Symbol	Unit	Value
Average daily radiance available (the most unfavorable month)	G	kWh/(m^2 d)	5
Head of pumping	h	m	45
Daily needs of water	Q	m^3	60
Efficiency of PV system	η_G		40%
Power of diesel genset	P_d	VA	4800
Consumption of diesel genset	F_d	l/h	1.02
Operating time of diesel genset	T_d	h	5
Power peak of PV module		Wc	55
Lifetime of PV array		Year	20
Lifetime of inverter dc/ac		Year	7
Lifetime of submersible motor-pump		Year	7
Lifetime of diesel genset		Year	7

Table 4
Economics parameters used in the financial evaluation

Parameters	Symbol	Unit	Value
Annual repair and maintenance cost of PV system		DA	37,000
Annual repair and maintenance cost of DG system		DA	39,500
Escalation rate of diesel	e		5%
Discount rate	d		8%
Interest rate	I		10%
Market price of diesel	F_d	DA/l	13.70

number of sunny days and the duration of sunshine in 1 day. It is supposed for the base case that the system operates with its full capacity where all water being able to be pumped by the system, is used.

The maintenance yearly cost of PV system of pumping considered in this study was estimated at 37 000.00 DA/year. The maintenance yearly cost of the DG system was estimated at 10% of the capital cost of the whole of the equipment.

The estimate of the unit cost of the m^3 of water delivered by the two systems is presented in Tables 5 and 6. Table 5 shows the capital cost, while Table 7 shows the payment of the capital by the annuities during the lifetime of the system. By examining these tables, we can note, in the first case, that the cost of the m^3 of water delivered by the DG system is 3.58 DA/m^3, which is distinctly lower than the cost of the m^3 of water delivered by the PV system of 8.73 DA/m^3. When the user of PV system profits from a subsidy, it acts positively on the cost of the m^3 delivered which becomes lower than the cost of the m^3 of water delivered by the DG system, beyond 85% of the capital, i.e. 3.46 DA/m^3. In Table 6, when the payment is done by annuities during the lifetime of PV system, the cost of the m^3 of water delivered by PV system is distinctly higher than the cost of the m^3 of water delivered by the DG system, 9.68 DA/m^3 against 3.71 DA/m^3. This is in the base case where the interest rate and the discount rate are equal 10 and 8%, respectively. The variations of the costs of the m^3 compared to the variations of other parameters will be studied in the analysis of sensitivity.

5.2.2. Analysis of sensitivity

The analysis of sensitivity is led to identify parameters which have a significant impact on the presented results. In addition to some standard parameters having an impact on the cost of the m^3 of water delivered more particularly by PV system of water pumping as such as head of the well, lifetime of the system, costs of the equipment and the saved consumption of the fuel [1,6,8,13,15,25,33]. For this analysis we targeted some typical parameters to the Algerian national policy can have an impact on costs of the m^3 of water delivered by the two systems of pumping. This analysis evaluates the impact of the variations of the following parameters:

- interest rate in the case of a loan near a financial organization,
- discount rate,
- utilization ratio,
- price market of the liter and escalation rate of the fuel.

In Fig. 7 we can see the effect of the interest rate on the cost of the m^3 when a loan is granted to the user by the financial organizations. The cost of the m^3 of water delivered by PV system is affected in a very significant way with the increase of the interest rate. That is mainly due to the lifetime which is

Table 5
Unit cost of water delivered by the two systems (cash payment at the first year)

Systems	Capacity	Without subsidy (DA)	With capital subsidy of PV system (DA)				
			F = 25%	F = 50%	F = 75%	F = 85%	F = 100%
PV pumping	2700 Wp	8.73	7.18	5.63	4.08	*3.46*	2.54
DG pumping	4800 VA	3.58					

Beyond a subsidy of 85% of the capital, the unit cost of water delivered by the PV system becomes more interesting than that delivered by the DG system.

Table 6
Unit cost of water delivered by the two systems (payment by annuity over the lifetime of the system)—base case

Systems	Capacity	Interest rate (%)	Discount rate (%)	Cost of m^3 (DA)
PV pumping	2700 Wp	10	8	9.68
DG pumping	4800 VA			3.71

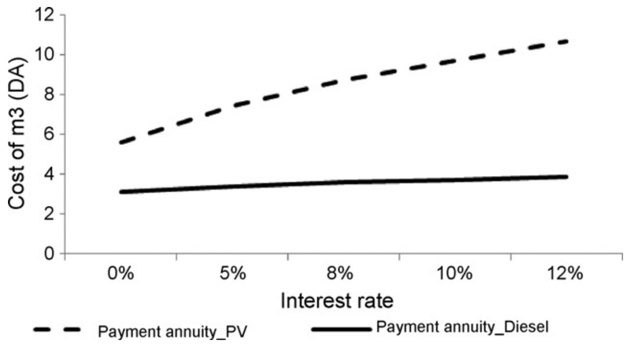

Fig. 7. Unit cost of the m^3 of water pumped by the two systems as a function of the interest rate.

much more significant than that of the DG system. If measures of incitement will be granted for loans without interest or very reduced for the renewable energy use, they would favor the use of the PV. For a null interest rate, the cost of the m^3 delivered by PV system is not very high compared to that delivered by DG system, 5.58 DA against 3.12 DA, respectively. On the other hand, for an interest rate of 10% (base case), the cost of the m^3 delivered by PV system is very high compared to that delivered by DG system, 9.68 and 3.71 DA, respectively.

Fig. 8, shows the effect of the discount rate on the cost of the m^3 of water delivered by the two systems by using the two modes of payment with an interest rate of 10%. We note that the cost of the m^3 is inversely proportional to the discount rate, and that the variations of the discount rate have a negligible effect on the DG system. For PV system, we note that for the mode of payment by annuities, the cost of the m^3 is very affected at the raised rates, decreases quickly and beyond 10% ($i = e$) present of the values which will be lower compared to the cost of the m^3

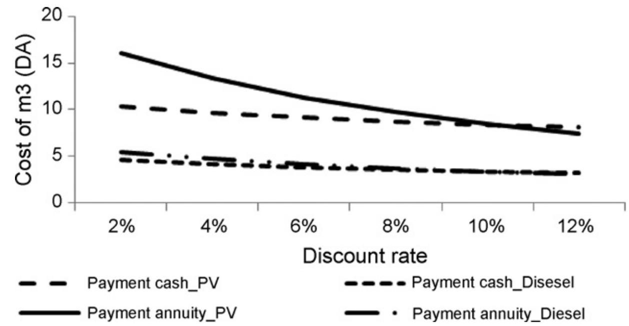

Fig. 8. Unit cost of the m^3 of water pumped by the two systems with the two modes of payment as a function of the discount rate.

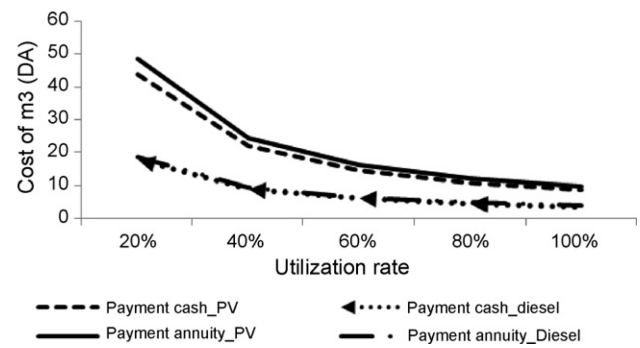

Fig. 9. Unit cost of the m^3 of water pumped by the two systems with the two modes of payment as a function of the utilization rate.

for a payment of the totality of the investment during the first year.

For a better efficiency of the system of pumping, a high utilization ratio is essential. Fig. 9 shows the effect of the utilization rate on the cost of the m^3 of water delivered by the two systems by using the two modes of payment. We note in Fig. 9 that the costs are high for low utilization ratios. That could be presented in various cases: oversizing of the system imposing its stop in middle of day, evaporation of water when the irrigation is done through the furrows...

Table 7 presents the effect of the escalation rate of the fuel on the costs of exploitation of the DG system, as well as on the cost of the m^3 of water delivered by the same system. It can be noted that the attraction of the PV for the water pumping compared to DG system improves with the escalation rate of the fuel price. Exploitation costs are considered as profit by using the PV system. These costs are even higher when the liter of fuel aligns on the average price practiced in Europe or in Morocco.

Table 7
Effect of diesel price escalation on the unit cost of water (DA)

Diesel price escalation (%)	5	10	20	25	0[a]	5[a]
Cost of exploitation 10^3 DA)	385	622	1843	3303	1830	6160
Cost of m^3—payment cash	3.58	4.12	6.91	*10.24*	6.87	*9.11*
Cost of m^3—payment by annuity	3.71	4.26	7.04	*10.38*	7.01	*9.24*

Beyond an escalation rate of 25%, the unit cost of water delivered by the DG system becomes more expensive than that delivered by the PV system. On other hand, if the price of the liter of diesel is about 1 € (average price practiced in Europe or in Morocco), the unit cost of water delivered by the PV system becomes more competing at escalation rate of 5% only.

[a] By considering the price of the liter of diesel equal to the average price practiced in Europe and Morocco (1 €).

6. Conclusions

This work presents a simple methodology to determine the technical performances of a PV system of water pumping as well as a financial study of two options of water pumping in Ghardaïa (Algeria). As it was noted, regions of the Algerian Sahara offer a non-negligible asset for use and the development of the solar energy through productive projects, if the economic and financial conditions follow.

Financial study of the two options has led to two modes of payments that present differences of costs for the PV system. For values of base-case of entry parameters supposed in this study, a significant difference has been observed in the unit cost of the water m^3 delivered by the two systems, mainly due to the important cost of investment of the PV system. The unit cost of the water m^3 delivered by the PV system is raised in comparison to the DG system, principal equipment of pumping in these regions.

We can also remark that costs of the m^3 of water of the PV system are greatly affected by the utilization ratio of the system, they increase for low utilization ratios.

Other important parameter is the escalation rate of the price of the fuel. While this rate is important, the attraction of the PV becomes important. Unfortunately and seen the displayed prices and sustained by the state, no other source of energy emerges and won't be able to compete with on no account the fossil energies at least until a escalation rate of 25%, Table 7. As we can see, if the prices of fuel were aligned on to those of in Europe, the cost of the m^3 pumped by the PV system would be more attractive with an escalation rate of 5%.

The only alternative for the development of PV systems and its use on a large scale, by taking into account specificities of the Algerian market is that the financial incentives with forms of significant subsidies and the financial loans with low interest rates. Null loans and the suppression of the various customs taxes to the profit of the equipments of renewable energies would be very beneficial to the development of these systems.

References

[1] Purohit P. Financial evaluation of renewable energy technologies for irrigation water pumping in India. Energy Policy 2007;35(6):3134–44.

[2] Abreu LA, Colle S, Glitz KLZ, Rüther R, Beyer HG. Isolated hybrid PV-diesel power plants design method. Rio de Janeiro: Rio-World Climat & Energy Event; 2003.

[3] Hadj-Arab A, Aït-Driss B, Amimeur R, Lorenzo E. Photovoltaic system sizing for Algeria. Solar Energy 1995;54(2):99–104.

[4] Hadj-Arab A, Benghanem M, Gharbi A. Dimensionnement de systèmes de pompage photovoltaïque. Revue des Energies Renouvelables 2005;8:19–26.

[5] Hadj-Arab A, Chenlo F, Benghanem M. Loss-of-load probability of photovoltaic pumping systems. Solar Energy 2004;76:713–23.

[6] Posorski R. Photovoltaic water pumps, an attractive tool for rural drinking water supply. Solar Energy 1996;58(4–6):155–63.

[7] Omer AM. Solar water pumping clean water for Sudan rural areas. Renew Energy 2001;24:245–58.

[8] Ghoneim AA. Design optimization of photovoltaic powered water pumping systems. Energy Conver Manage 2006;47:1449–63.

[9] Hadj-Arab A, Chenlo F, Mukadam K, Balenzategui JL. Performance of PV water pumping systems. Renew Energy 1999;18:191–204.

[10] Hamidat A, Benyoucef B, Hartani T. Small-scale irrigation with PV water pumping system in sahara region. Renew Energy 2003;28(7):1081–96.

[11] Firatoglu Z, Yesilata B. New approaches on the optimization of directed coupled PV pumping systems. Solar Energy 2004;77:81–93.

[12] Short T, Oldach R. Solar powered water pumps: the past, the present and the future. J Solar Energy Eng 2003;125(1):76–82.

[13] Odeh I, Yohanis YG, Norton B. Economic viability of photovoltaic water pumping systems. Solar Energy 2006;80:850–60.

[14] Thomas MG. Water pumping: the solar alternative. SAND8T-0804. Albuquerque, NM: Sandia National Laboratories Photovoltaic Systems Design Center; 1993.

[15] Celik AN. Techno-economic analysis of autonomous PV-wind hybrid energy systems using different sizing methods. Energy Conver Manage 2003;44:1951–68.

[16] Hadj-Arab A, Benghanem M, Chenlo F. Motor-pump system modelization. Renew Energy 2006;31:905–13.

[17] Benlarbi K, Mokrani L, Naït-Saïd M. A fuzzy global efficiency optimization of a photovoltaic water pumping system. Solar Energy 2004;77:203–16.

[18] Kolhe M, Joshi JC, Kothari DP. Performance analysis of a directly coupled photovoltaic water-pumping system. IEEE Trans Energy Conver 2004;19:613–8.

[19] Yaho Y, Baustameute P, Ramshow RS. Improvement of induction motor drive systems supplied by photovoltaic array with frequency control. IEEE Trans Energy Conver 1994;8(1):47–52.

[20] Zaki A, Eskander M. Matching of photovoltaic motor-pump systems for maximum efficiency operation. Renew Energy 1996;7(3):279–88.

[21] Eskander M, Zaki A. A maximum efficiency photovoltaic induction motor pump system. Renew Energy 1997;10(1):53–60.

[22] Olorunfemi O. Analyse of current source induction motor drive fed from photovoltaic energy source. IEEE Trans Energy Conver 1991;6(1):99–106.

[23] Odeh I, Mahmoud M. Field results of photovoltaic water pumping systems. Appl Solar Energy 1995;31(3):20–9.

[24] Alonso-Abella M, Lorenzo E, Chenlo F. PV water pumping systems based on standard frequency converter. Prog Photovoltaic Res Appl 2003;11:1–13.

[25] Hamidat A. Simulation of the performance and cost calculations of the surface pump. Renew Energy 1999;18:383–92.

[26] Liu BYH, Jordan RC. The interrelationship and characteristic distribution of direct, diffuse and total solar radiation. Solar Energy 1960;4:1–19.

[27] Klein SA. Calculation of monthly average insolation on tilted surfaces. Solar Energy 1977;19:325–9.

[28] Singer S, Rozenshtein B, Saurazi S. Caracterization of PV array output using a small number of measured parameters. Solar Energy 1984;32(5):603–7.

[29] Chan DSH, Philips JR, Phang JCH. A comparative study of extraction methods for solar cell model parameters. Solid State Electron 1986;29(3):329–37.

[30] Akbaba M, Alattawi MAA. A new model for *I–V* characteristic of solar cell generators and its applications. Solar Energy Mater Solar Cells 1995;37:123–32.

[31] Blaesser G, Ross E. Extrapolation of outdoor measurement of PV array *I–V* characteristics to standard test conditions. Solar Cells 1988;25:91–6.

[32] Brandemuehl MJ, Beckman WA. Economic evaluation and optimization of solar heating systems. Solar Energy 1979;23:1–10.

[33] Chandrasekar B, Kandpal TC. Effect of financial and fiscal incentives on the effective capital cost of solar energy technologies to the user. Solar Energy 2005;78:147–56.